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In re application of	
Johannis J. Den Boer et al.	
Serial No. 10/621,506	Group Art Unit: 1725
Filed July 17, 2003	Examiner: Kiley S. Stoner
EMAT WELD INSPECTION	November 19, 2004

COMMISSIONER FOR PATENTS
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Sir:

CLAIM TO PRIORITY

Applicant(s) reaffirm the claim for the benefit of filing date of the following foreign patent application referred to in Applicant's Declaration:

European Application Serial No. 02077914.6 filed July 17, 2002.

A copy of the application certified by the European Patent Office is enclosed.

Respectfully submitted,

Johannis J. Den Boer et al.

By Eugene R. Montalvo

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Bescheinigung | Certificate | Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

02077914.6

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

R C van Dijk

Anmeldung Nr:
Application no.: 02077914.6
Demande no:

Anmeldetag:
Date of filing: 17.07.02
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Anmelder/Applicant(s)/Demandeur(s):

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Emat weld insepction

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Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

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EMAT WELD INSPECTION

Background of the invention

The invention relates to a method and system for inspecting welds by means of an Electro Magnetic Acoustic Transducer (EMAT) assembly.

The use of EMAT assemblies for inspecting welds is known from US patents 5,439,157 and 5,474,225. In the known EMAT weld inspection methods a robotic transport apparatus containing EMAT transmitting and receiving coils is automatically positioned at one side of a just-completed weld whereupon the EMAT transmitting coil transmits ultrasonic SH shear waves towards the weld and the EMAT receiving coil transduces any ultrasonic SH shear waves reflected by the weld in a signal which is used to signal the presence of defects in the weld on the basis of the received signal. The robotic transport apparatus is in use moved along the surface of one of the welded plates parallel to the weld and may be connected to a control unit which automatically adjusts the settings of the welding apparatus which moves ahead of the EMAT weld assembly. The use of a robotic transport apparatus is not practical for inspection of welds between tubulars since it requires the robotic transport apparatus to rotate around a welded tubular, which is time consuming and requires the use of a fragile robotic tool.

The use of EMAT devices for weld and/or pipe inspection is also disclosed in
US Patent No. 5,652,389 to Barnes, et. al.,

US Patent No. 5,760,307 to Latimer et. al., WO Patent No. 02/40986 and US patent 5,808,202 to Passarelli. Barnes discloses a pulse-echo technique and apparatus for inspection of inertia welds in plat-plates using EMAT. Latimer discloses a method to eliminate root and crown signals using crossed or collinear EMATs, and Passarelli discloses a pulse-echo technique for the inspection of cylindrical objects including rods and tubes.

The device disclosed by Passarelli has the disadvantage that it is has a fixed ring-shape construction, which cannot be put readily around the tubulars and the weld at the rig floor without the danger of damaging the device or at the expense of substantial time delays. Another disadvantage to this arrangement is the geometry of the electromagnets, the transmitter and the receiver coil, which does not provide a 100% inspection of the weld around the circumference of the pipe, as the aperture of the transmitters is smaller than the ultrasonic field at the weld region. Rotating the tubular could mitigate the disadvantage, but that is not possible when the tubulars are welded at the rig floor, as will be explained below. An additional, difficulty posed by this and other prior art is that the weld is inspected by pulse-echo reflection measurement only. However, to prevent miss-interpretation of the reflected signals, e.g. due to diffraction or scatter at the weld, it is preferred to measure both reflection and transmission at the same time using at least two EMATs positioned upstream and downstream from the weld.

It is an object of the present invention to provide an improved method and system for inspecting welds by means of an EMAT assembly which does not require the use

of robotic transport apparatus and which can be activated to inspect the weld on any irregularities and/or the presence of oxide inclusions instantly after the weld is made throughout the length of the weld.

Summary of the Invention

The tubular weld inspection method according to the invention comprises arranging a series of electromagnetic acoustic transducer (EMAT) assemblies in circumferential direction adjacent to an inner and/or outer surface of at least one of the welded tubular ends and inducing the EMAT assemblies to transmit sequentially (ie. individually or grouped) or simultaneously acoustic shear wave signals in different modes and angles towards the weld and to detect the shear waves reflected by and/or passing through the weld such that at least a substantial part of the weld is scanned by the EMAT assemblies .

Optionally, the EMAT assemblies comprise a ring shaped assembly of EMAT transmitters and a ring shaped assembly of EMAT receivers, which is arranged between the weld and the ring shaped assembly of EMAT transmitters.

In a preferred embodiment the EMAT assemblies comprise ring shaped assemblies of EMAT transmitter and receiver assemblies at both sides of the weld when seen in longitudinal direction of the welded tubulars.

It is preferred that each of the EMAT transmitter and receiver assemblies comprises a matrix of EMAT transducers which at least partly overlap each other in a circumferential direction.

The EMAT transducers of at least one matrix may be stacked on top of each other in a radial direction relative to the tube wall. Alternatively, the EMAT transducers of at least one matrix are staggered in a

substantially longitudinal direction relative to the tube wall.

In one embodiment the EMAT assembly is arranged on a carrier body, which is arranged in the interior of at least one of the welded tubulars. This embodiment of the EMAT assembly can also be used for inspection of welds in-situ, e.g. downhole, or in laying barge pipelines, either immediately after welding or some time later, e.g. to inspect the quality of the welds after several years service.

In an alternative embodiment the EMAT assembly is arranged on a carrier sleeve which surrounds at least one of the welded tubulars and which can optionally be split into at least two sleeve segments after completion of the welding operation. This embodiment can also be used for inspection of welds in-situ, e.g. at the rig floor or in laying barge pipelines.

The EMAT tubular weld inspection method and assembly is able to inspect the quality of forge welded tubulars instantly after the forge weld has been made.

The EMAT assembly according to the invention comprises a series of electromagnetic acoustic transducers which are in use distributed in a circumferential direction adjacent to an inner and/or outer surface of at least one of the welded tubular ends and are configured to transmit sequentially or simultaneously acoustic shear wave signals in different modes and angles towards the weld and to detect the shear waves reflected by and/or passing through the weld such that at least a substantial part of the weld is scanned by the EMAT assembly.

In an embodiment, the assembly comprises at least two longitudinally spaced ring shaped arrays of EMAT

transmitters and receivers such that the ring shaped arrays of EMAT receivers are located between the ring shaped arrays of EMAT transmitters.

Description of preferred embodiments

Some preferred embodiments of the EMAT weld inspection method and assembly according to the invention will be described in more detail with reference to the accompanying drawings, in which:

Figures 1a and 1b show side and top views of a forge welding apparatus which is equipped with an EMAT weld inspection assembly according to the invention.

Fig.2 shows a longitudinal section view of a spear which is inserted into a pair of forge welded tubulars and which carries ring shaped assemblies of EMAT transmitters and receivers at each side of the weld;

Fig.3 shows a longitudinal sectional view of a weld between tubulars through which an ultrasonic signal is transmitted

Fig.4a-f show a three-dimensional view of an EMAT transmitter and receiver assembly and how the acoustic signal is transmitted into the tubular wall; and

Fig.5 shows various suitable configurations of the EMAT transmitter and receiver assemblies.

The traditional method of connecting lengths of OCTG (Oil Country Tubular Goods), whether they are for downhole casing or tubing, is to use a threaded connection or another form of joining based on a suitable welding technique like explosive welding, shielded active gas welding, flash butt welding, etc.

In the case of welding, the presence of certain defects will reduce the strength and thus the safety and structural integrity of the downhole oil or gas tubular. Therefore, proper inspection of the weld for flaws or

other irregularities is mandatory. It is preferred to inspect the weld immediately after the weld is made using a non-destructive test technique.

At the rig-floor the tubulars are kept aligned in an upright and fixed position during welding using pipe grippers as shown in Fig 1 and 2. After inspection and approval of the weld quality the tubular is lowered in to the wellbore, and another piece of tubing or casing (minimal length 10 meters) is positioned on top of it and welded, etc. To minimise the loss of rig-time and to enhance safety at the rig-floor, it is preferred to perform the inspection of the weld in a fully automatic way, starting immediately after the weld is made and completed in a minimum of time. For well integrity reasons it is mandatory to inspect the weld over its full length along the circumference of the pipe.

At present, a range of well known technologies are available for inspection of butt welds in tubes and pipes, based on x-ray, ultrasonic inspection techniques, EMAT, eddy current inspection and their derivite techniques as SLOFEC, remote field eddy current, partial saturated eddy current, etc.

However, the requirement for inspection of tubulars intended for use in downhole environments presents novel challenges that disqualify many techniques and/or configurations. These are requirements for:

a. rapid completion of testing on relatively poorly prepared surfaces, with the weld still hot.

b. fully automatic operation of the testing equipment.

c. immediate feedback to allow assessment for acceptance or rejection of the weld.

d. integration with the welding device

e. safe operation in a potentially hazardous environment.

The present invention enables the use of EMAT weld inspection technology at the rig-floor.

EMAT (electromagnetic acoustic transducer) inspection is a known inspection technique, in which interaction between a magnetic and electromagnetic field induces acoustic energy in the test piece. The generated acoustic wave is reflected by anomalies or defects and can be detected by a suitable receiver. The receiver can be either a conventional piezo-electric transducer or an EMAT. To validate the magnetic coupling of the transmitting EMAT a receiver on the other side of the weld can be applied as a transmission check.

In this case the relative strength of this energy is altered by the presence of defects and is used to identify defects.

In the method according to the invention novel transmission and receiver EMAT assemblies are described which are suited to inspection of forge-welded pipes. To ensure correct and accurate positioning of the EMAT probes, a novel design has been made that allows integration into the forge-welding machine or into the internal spear used for the alignment of the tubulars while welded together.

With the aid of the accompanying Figures 1 to 5, the preferred embodiments are explained in more detail.

Reference is now made to Figures 1 and 2. A non-destructive testing method and apparatus is disclosed comprising two EMAT probes 7,8. It is required that the EMAT probes 7,8 are positioned either above the weld, below the weld or, preferably, above and below the weld and that they are in close proximity (typically no

more than 2 mm from) the pipe wall. Each EMAT probe consists of a transmitter and receiver pair. In all cases the receiver is positioned adjacent to the transmitter but between the transmitter and the weld. The EMAT probes can be integrated into the gas shield chamber 3 of the forge-welding machine (fig.1) or into the internal spear 25 (fig.2).

The EMAT assembly is ring-shaped but can be segmented into at least 2 parts. During the whole welding and inspection operation, the pipes 1 are kept in a fixed position, they cannot rotate, using pipe grippers 4. The gas shield chamber of the forge-welding machine 3 is closed during that time.

Control electronics, pre-amplifiers, signal pre-processing etc. is located close to the electromagnets and the T/R coils in 16. Active cooling (not shown) for the electromagnets is also provided.

In use, each R/T pair 7,8 is activated and controlled by an electronic switch box in 16. A signal is generated by each of the transmitters 7 and generated toward the weld 6, the adjacent receiver 8 detects this signal for calibration purposes and the signal continues to propagate toward the weld. If there is a defect in the weld then the signal is reflected back toward the transmitter whereupon the receiver will detect it and report a defect

When applied together with the forge-welding machine the EMAT probes 7, 8 are automatically centred around the pipe wall 1, using a spring system 9, when the gas shield chamber 3 is closed. The surface of the probes 7,8 are protected by a thin shim, typically 0.1mm metal although other wear resistant material can be employed.

When applied together with the internal spear: The use of an internal spear 25 for e.g. forge welding has been described previously. In this application EMAT inspection probes 7, 8 are positioned around a housing that is an extension of the previous internal spear housing or which may be attached as an accessory to that housing. Provision is made in the housing for the permanent or electromagnets required for EMAT inspection and a suitable power supply, electronic switching box and data umbilical is provided.

The simplest and preferred embodiment requires that the spear is pre-positioned in one of the pipes 2 to be welded. This allows inspection probes to be in good contact with the pipe wall without a drift requirement and can be accomplished by using a simple backing material such as a foam rubber. Where the inspection device needs to be drifted into position then the probes 7,8 are positioned against the pipe walls 3 using an activation method of which there are several possibilities.

An almost identical configuration can be used for inspection of welds in-situ, e.g. downhole or in laying barge pipelines, either immediately after welding or some time later, e.g. to inspect the quality of the welds after several years service.

The EMAT probes 7, 8 are stand-by during the welding operation and start the inspection immediately after the welding process is completed and the local temperature of the weld is low enough, e.g. 700C.

Reference is made to Figure 3. The preferred embodiment requires the use of a series of EMAT receivers e.g. R2 on the opposite side of the weld to the transmitters, e.g. T1. In the event that there is no

defect present this second matching receiver R2 will detect a strong signal when the signal has passed through the weld. If this receiver is not present then a larger degree of uncertainty exists with regard to defect sizing because reflected signals may scatter and be lost, were this to happen the size of a defect may be incorrectly/misleadingly reported.

Besides validation, the configuration provides means for gain control of the receiving coil e.g. R1. The advantage of the preferred embodiment of the present invention is the fact that the EMAT system can be operated in different mode. For example, by altering the relative angle between the pipe, magnetic and electromagnetic field it is possible to cause the steel to vibrate in just any direction. One of the advantages of this is that it allows the full body of the pipe wall to be "vibrated"and for the full body vibration to travel along the pipe parallel to the pipe wall. This prevents 'skipping' as indicated in fig. 3 and improves the signal-to-noise ratio significantly. The same process is repeated for transmitter T2 thus giving redundancy to the entire configuration.

Reference is made to Figure 4a,b,c. The transducer and receivers 7,8 are composed of a set of laminated electromagnets 17 which can be controlled individually, in groups or all at the same time. The individual electromagnets 17 are separated form each other by a thin spacer 18. In the preferred embodiment the individual electromagnets can be put together with legoland type connections 4b. This construction enables the EMAT probes 7,8 to be re-configured for different pipe diameters. The ends of the EMAT probes 7,8 are covered with a suitable face protection material 15, e.g. Vespel, to prevent

damaging and fouling of the transducer and receiver assemblies. At this location (on both sides) the flexible transducer and receiver coils 23 are fixed mounted and can move freely to adapt to diameter changes. The EMAT probes 7,8 are separated by means of another dielectric spacer 11. The transducer and receiver coils 12, 13 are placed inside a recessed area or at the surface of the electromagnet elements.

Reference is made to Figure 4d. An electrostatic shield 22 is used to safeguard the EMAT receiver coil from the effects of undesirable electric interference. The electrostatic shield, e.g. mu-metal, grounded, acts as a barrier to protect the EMAT receiver coil from electrostatic interference and radio frequency interference (EMI/RFI).

Reference is made to Figure 4e and 4f. Here the means are disclosed by whom to create a focal area (aperture) of the ultrasonic wave 21 that has an identical size as one or more of the electromagnet elements 17. One or more (could even be all) electromagnet elements 17 can be magnetised thus forming a larger magnetic field than from one single electromagnet element 17. The electromagnet elements 17 can be switched on and off individually, in groups or all at the same time, using the control electronics in 16.

Reference is made to Figure 5. Using novel design, use and control of meander-loop coils elements 23 provide the option to select different modes of operation and transmission angles of the ultrasonic wave, allowing a full inspection of the entire weld all around the circumference of the pipe.

Within the ring of electromagnets a transmitting or receiving coil 13, 14 is present 5a, which can be a

length of wire or build up out of separate meander-loop coil elements 5b. The transmitting or receiving coil elements 13,14 can be controlled separately to obtain either one large meander-loop 5c or a phased array to generate an angled ultrasonic wave 5d. The receiver coil elements 23 are equipped with suitable pre-amplifiers 24. They can be processed separately or combined using the control electronics in 16.

Furthermore, by introducing small coil elements 23 a number of additional different configurations 5e, 5f, 5g, 5h can be created for different inspection purposes.

Basic configurations are:

(I)a long meander loop coil (i.e. circumferential direction) 5f,

(II)a short meander loop coil (i.e. radial direction) using a single layer of coils 5g.

(III)two or more staggered layers 5h of can be used to create an improved coverage, additional depth direction and better signal-to-noise ratio. The overall thickness of the staggered layers should be small, in the order of 1 mm.

Variations are possible.

The preferred embodiment is accomplished by sandwiching two or more layers of flexible probe around the full circumference of the pipe. An alternative embodiment would have the layers of EMAT probes positioned in a similar staggered pattern but with one layer above the other. Preferably the transmitter and receiver coils are put on a flexible carrier or substrate, which can be exchanged readily at the rig-floor.

CLAIMS

1. A method for inspecting welds between welded tubular ends, the method comprising arranging a series of electromagnetic acoustic transducer (EMAT) assemblies in circumferential direction adjacent to an inner and/or outer surface of at least one of the welded tubular ends and inducing the EMAT assemblies to transmit sequentially or simultaneously acoustic shear wave signals in different modes and angles towards the weld and to detect the shear waves reflected by and/or passing through the weld such that at least a substantial part of the weld is scanned by the EMAT assemblies .

2. The method of claim 1, wherein the EMAT assemblies comprise a ring shaped assembly of EMAT transmitters and a ring shaped assembly of EMAT receivers, which is arranged between the weld and the ring shaped assembly of EMAT transmitters.

3. The method of claim 2, wherein the EMAT assemblies comprise ring shaped assemblies of EMAT transmitter and receiver assemblies at both sides of the weld when seen in longitudinal direction of the welded tubulars.

4. The method of claim 2 or 3, wherein each of the EMAT transmitter and receiver assemblies comprises a matrix of EMAT transducers which at least partly overlap each other in a circumferential direction.

5. The method of claim 4, wherein the EMAT transducers of at least one matrix are stacked on top of each other in a partially overlapping pattern in a radial direction relative to the tube wall.

6. The method of claim 4, wherein the EMAT transducers of at least one matrix are staggered in a substantially longitudinal direction relative to the tube wall.

7. The method of any preceding claim wherein the EMAT assembly is arranged on a carrier body which is arranged in the interior of at least one of the welded tubulars.

8. The method of any one of claims 1-6, wherein the EMAT assemblies are arranged on a carrier sleeve which surrounds at least one of the welded tubulars and which can optionally be split into at least two sleeve segments after completion of the welding operation.

9. The method of any preceding claim, wherein the EMAT assemblies are operated to inspect the quality of forge welded tubulars instantly after the forge weld has been made.

10. An EMAT assembly for inspecting welds between welded tubular ends, the assembly comprising a series electromagnetic acoustic transducers which are in use distributed in a circumferential direction adjacent to an inner and/or outer surface of at least one of the welded tubular ends and are configured to transmit sequentially or simultaneously acoustic shear wave signals in different modes and angles towards the weld and to detect the shear waves reflected by and/or passing through the weld such that at least a substantial part of the weld is scanned by the EMAT assembly .

11. The EMAT assembly of claim 10, wherein the assembly comprises at least two longitudinally spaced ring shaped arrays of EMAT transmitters and receivers and wherein the ring shaped arrays of EMAT receivers are located between the ring shaped arrays of EMAT transmitters.

A B S T R A C T

EMAT WELD INSPECTION

A method for inspecting welds between welded tubular ends comprises arranging a series electromagnetic acoustic transducer (EMAT) assemblies in circumferential direction adjacent to an inner and/or outer surface of at least one of the welded tubular ends and inducing the EMAT assemblies to transmit sequentially or simultaneously acoustic shear wave signals towards the weld and to detect the shear waves reflected by and/or passing through the weld such that at least a substantial part of the weld is scanned by the EMAT assemblies instantly after the weld is made.

(Fig.1b)

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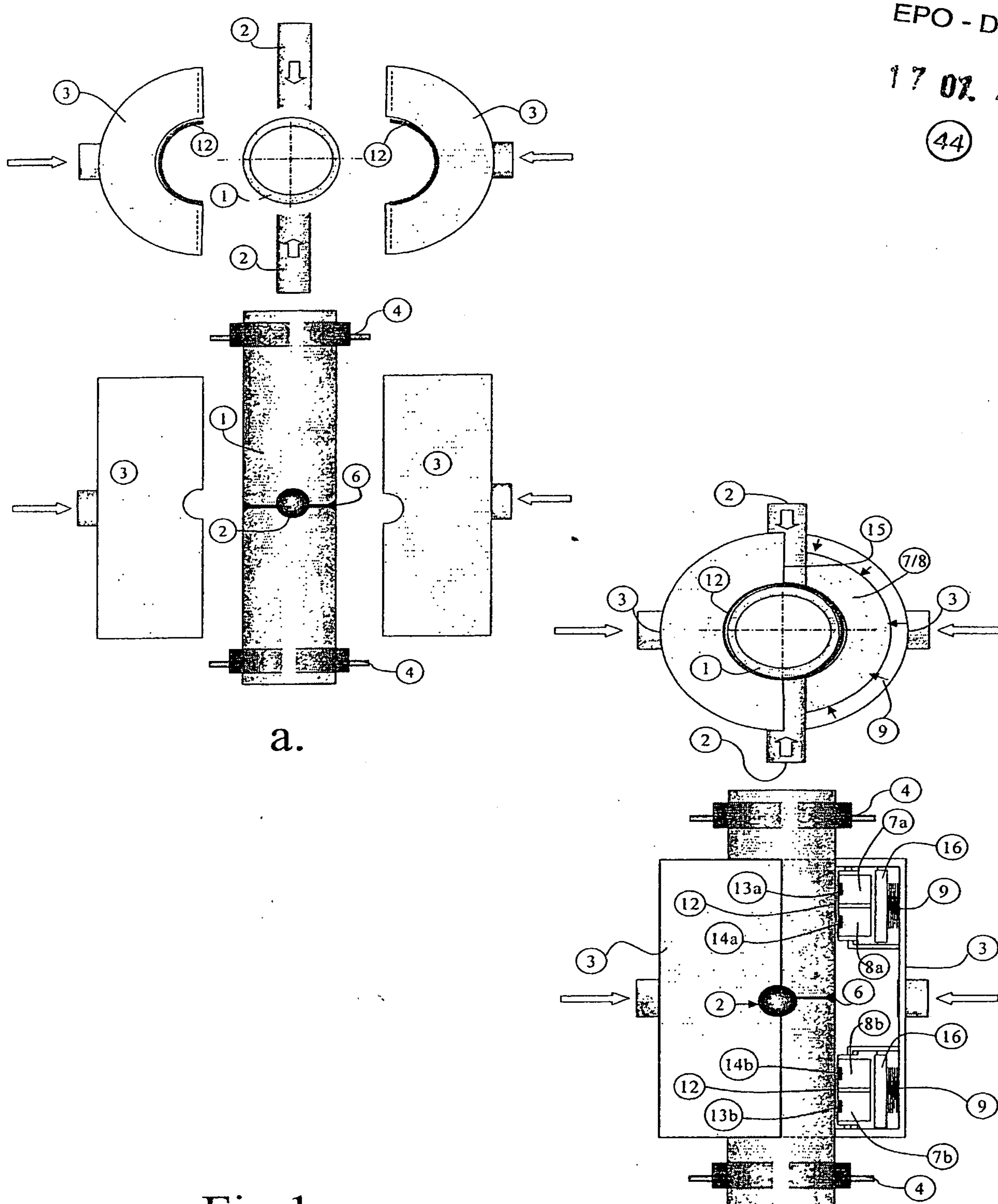

a.

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Fig.1

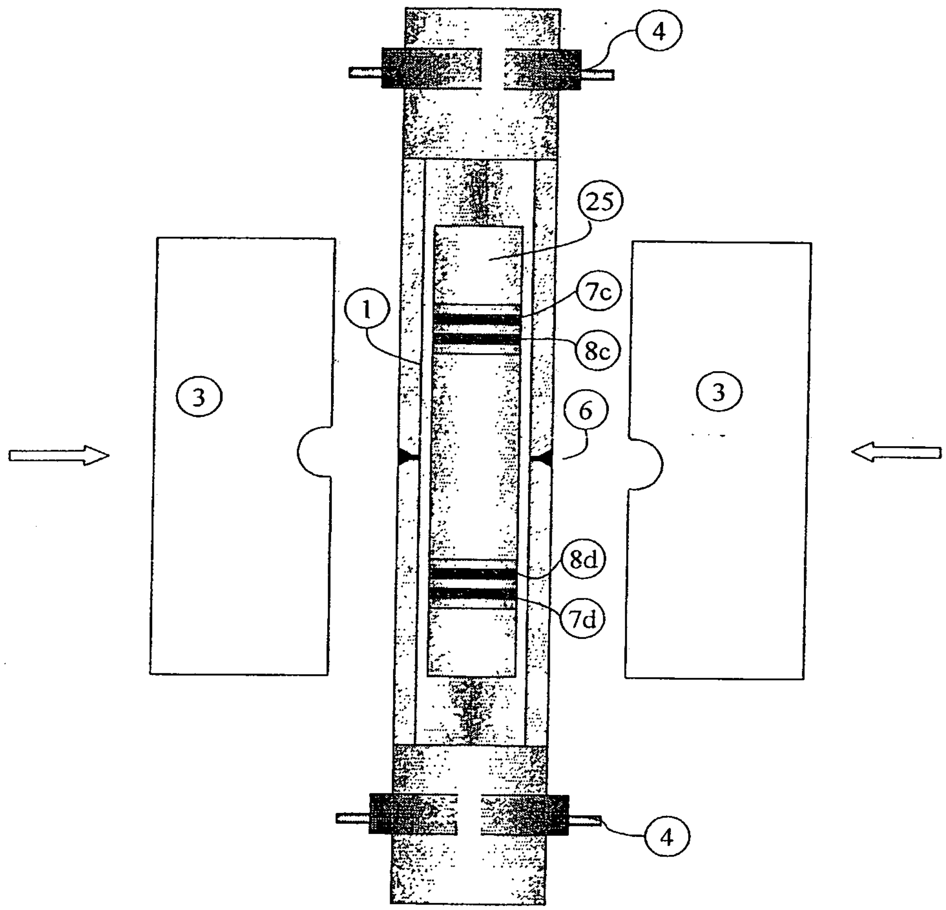

Fig. 2

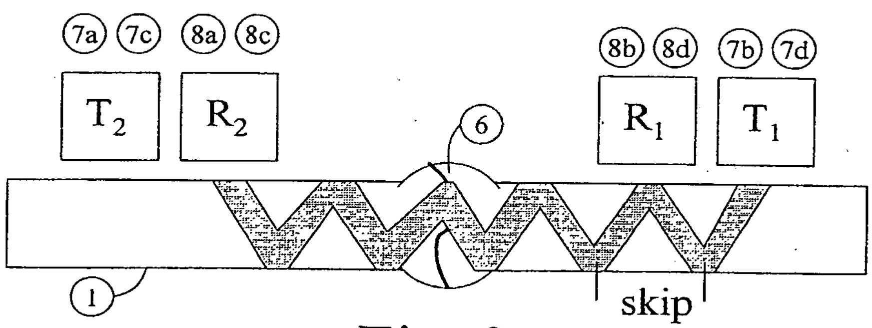

Fig. 3

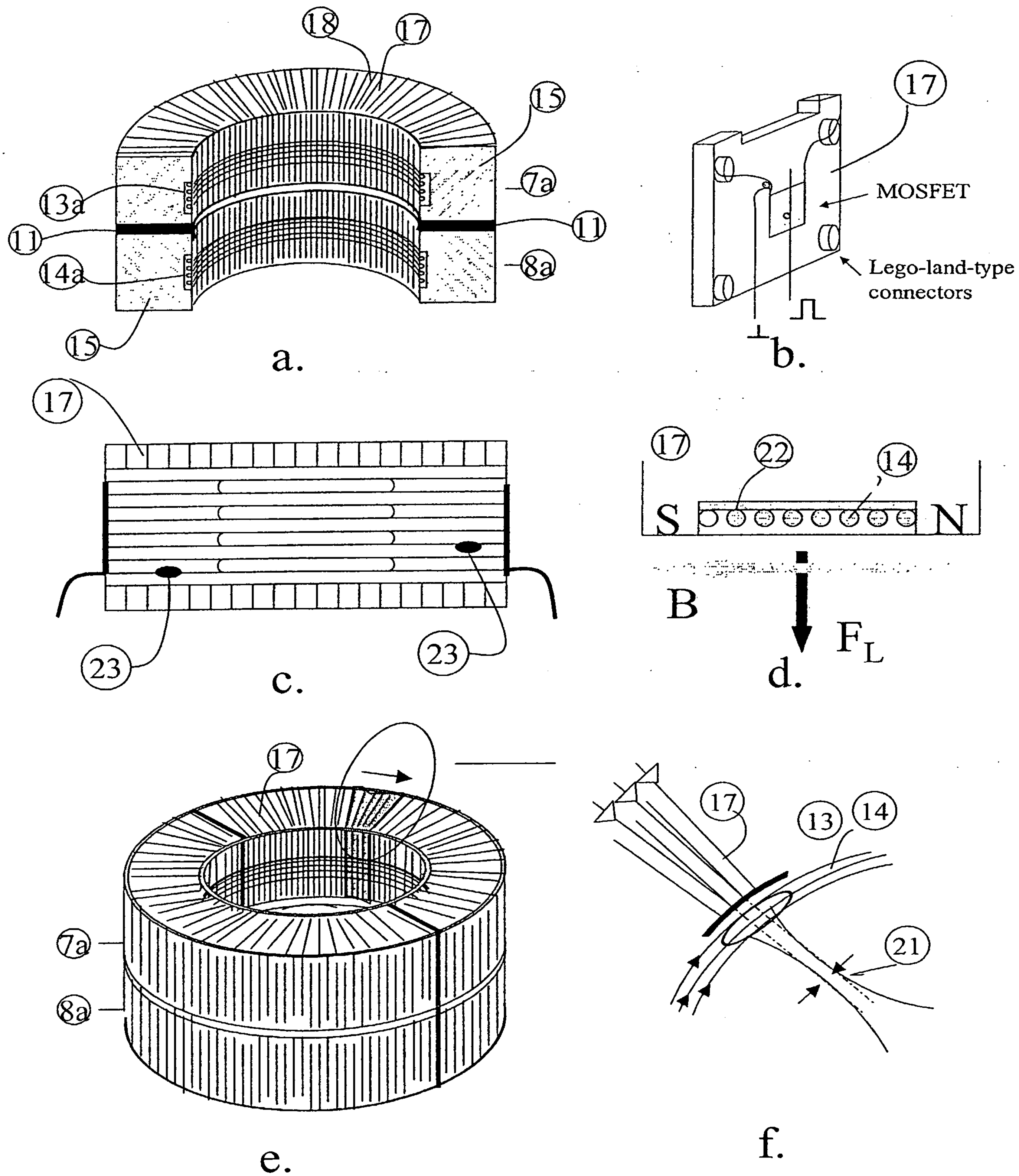
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Fig. 4

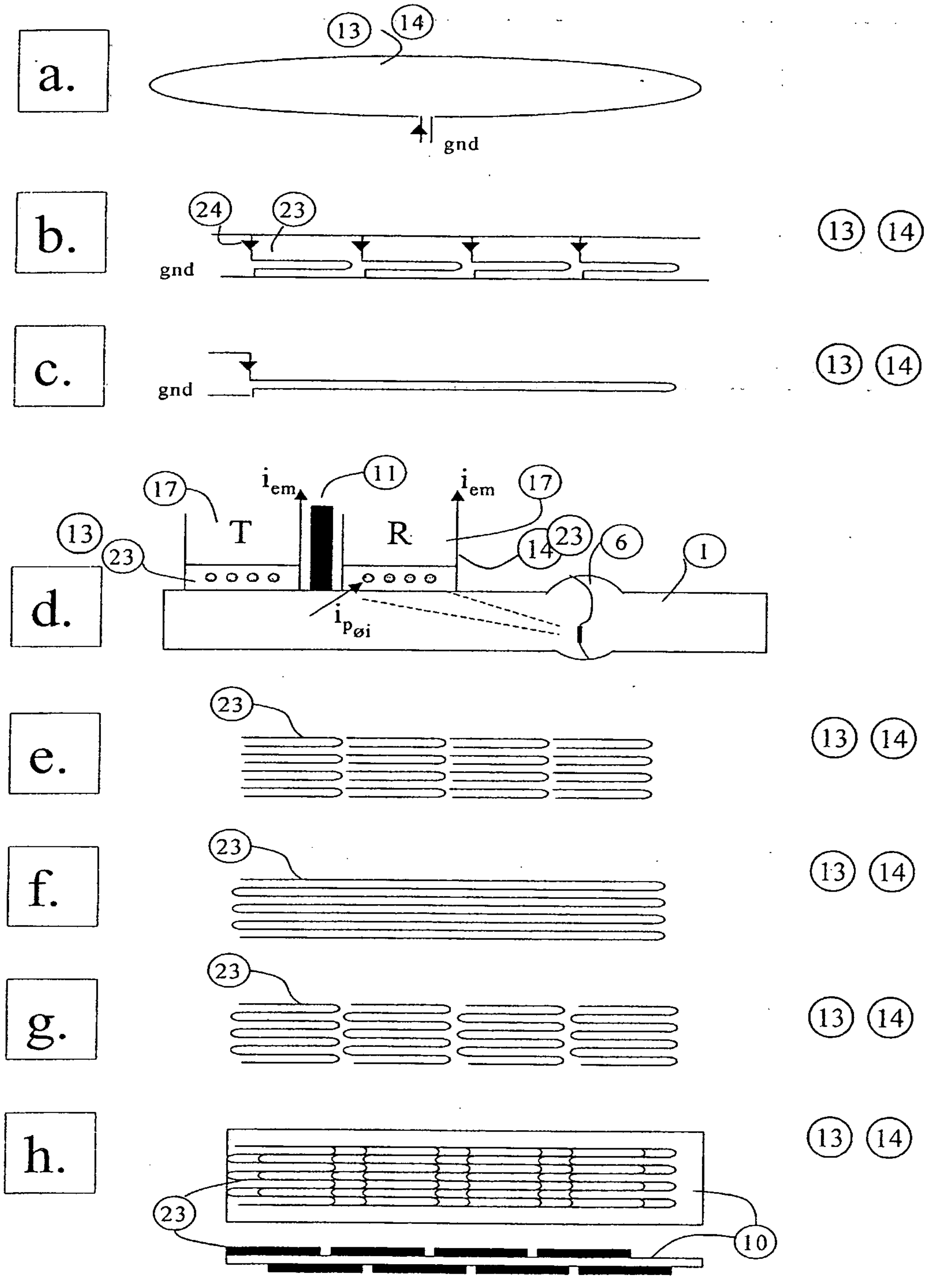

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Fig. 5